IMPACT OF ECONOMIC GROWTH AND INDUSTRIAL ACTIVITIES ON AIR QUALITY IN CHINA: EVIDENCE FROM 118 CITIES

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ABSTRACT

In the past few decades, Chinas tremendous economic and social development, and the lack of environmental regulation, has made environmental quality a serious concern. Now the government is going to develop western China and pushes the One Belt One Road multibillion-dollar infrastructure project. In the context of environmental degradation and China's new push for an "ecological civilization" in the new normal, to estimate the environmental cost of economic development in China is very important.

A rich literature that examines the effect of economic growth on air quality degradation suggests that there is an inverted-U shaped relationship between the two. However, most of the previous studies of this relationship concentrate on finding the turning point of the inverted-U and do not focus on quantifying the impact of economic growth and industrial activities on environmental quality. Neither do they address the potential of an endogenous problem in the relationship. This study estimates the impact that economic growth and industrial activities had on Chinas air quality from 2000 to 2012, and it predicts the future impact of economic growth in western China. To deal with the potential of endogeneity, this study constructs instrumental variables (IV) for GDP and industrial output by using the GDP of trading partner countries. With data from 118 Chinese cities, this study identifies the impact of economic growth and industrial output on air quality in China and similar developing areas. The results suggest a quadratic relationship between economic growth and air quality degradation. The estimated marginal impact is stronger than in most previous studies: a 10% increase in secondary industry GDP is associated with a 5% in-

crease in air pollutant concentrations, on average. This impact is largely driven by pollution-intensive industries in the secondary sector.

BIOGRAPHICAL SKETCH

Jingyuan Wang was born in Beijing, China. She graduated from Peking University in 2014, where she received her B.S. in environmental sciences and B.A. in economics. In May 2017, she will graduate from the master program of applied economics and management at Cornell University. Jingyuan is currently a Pre-Doctoral Fellow at EPIC and works on the Social Cost of Carbon project.

This document is dedicated to all Cornell graduate students.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Since 2000, Chinas economic development of its western region-and more recently the One Belt One Road multibillion-dollar infrastructure project to revive Silk Road trade routes to the West, begun in 2013-is having a noticeable effect on air quality degradation. In the past few decades, Chinas tremendous economic and social development, and the lack of environmental regulation, has made environmental quality a serious concern. The annual particulate matter (PM2.5) concentration in China was 54 $\mu g/m^3$ in 2013; the World Health Organization (WHO) air quality guideline is 10 $\mu g/m^3$. More than 99% of Chinas population (very nearly 100% of the population) lives in places where mean annual concentrations of PM2.5 exceed the WHO guideline value (World Bank, 2013). If the government is going to develop western China, then policymakers should be aware of the potential impact that development will have on air quality.

The negative impacts of air pollution on human health, economic activities, and social welfare are not speculative; they have been proven by both economists and scientists. For example, Chay (1999) suggests that a 1 mg/m^3 increase in particulates will result in about 4-8 more infant deaths per 100,000 [3]. In the context of environmental degradation and China's new push for an "ecological civilization" in the new normal, to estimate the environmental cost of economic development in China is very important.

Growing evidence demonstrates that air quality degradation is associated with economic development and finds an inverted-U shaped relationship between the two, which is described by the environmental Kuznets curve (EKC). However, limited studies concentrate on China or other developing countries. What's more, most of the previous studies of this relationship concentrate on finding the turning point of the inverted-U and do not focus on quantifying the impact of economic growth and industrial activities on environmental quality.

Most of the existing studies, such as Song (2008) [24] and Cole (2004) [4], use emission amounts instead of pollutant concentrations as their depend variables. Although emissions are more directly related to economic activities, concentrations are more applicable to environmental status and the costs of air quality degradation. This study uses air quality index (AQI) as the dependent variable.

None of the previous studies address the potential of an endogenous problem in the relationship between economic growth and air quality degradation. Unobservable factors, such as environmental regulation policies, affect both industrial output and air quality, thereby leading to underestimation of the impact of industrial activities on air quality. For example, the Five Year Plans and environmental-quality control policies are related; policymakers are aware that economic development causes environmental degradation. Therefore, these policies might influence both air quality and economic status. Unfortunately, these policies are always unobservable. Therefore, this research constructs instrumental variables to single out the exogenous impact of economic growth on environmental quality in China.

This study estimates the impact of economic growth on air quality degradation in China from 2000 to 2012 and predicts the impact of economic growth on air quality in western China in the near future. Economic activities of export destination countries are applied as instrumental variables for economic growth and industrial outputs of Chinese cities. The results suggest a quadratic relationship between economic growth and air quality degradation, but the estimated marginal impact is stronger than results from most studies: a 10% increase in pollution-intensive industrial output is associated with a 5% increase in air pollutant concentrations, on average. Furthermore, this study separates the secondary sector into pollution-intensive industries and non-pollution-intensive industries and finds that pollution-intensive industries contribute most to the negative impact of economic growth on air quality.

The paper proceeds as follows: Chapter 1 reviews existing literature on the impact of economic growth on air quality degradation; Chapter 2 describes the data patterns; Chapter 3 explains the empirical estimation strategies and IV constructions; Chapter 4 describes the estimation results; and Chapter 5 and Chapter 6 discuss the results and their implications.

1.2 Literature Review

Numerous studies have tested the relationship between economic development and air quality degradation. Some focused more on theoretical explanations of the Environmental Kuznets Curve, while some studies used empirical evidence to demonstrate the relationship. Recently, a growing number of empirical studies have begun to focus on China's air quality. This section will briefly summarize the explanations and mechanisms of how economic growth could influence air quality, in order to identify the variables that would need to be controlled or added into the econometric model in this research. Then we will summarize previous empirical studies, with particular emphasis on studies of China.

Theoretical Studies on Environmental Kuznets Curve Hypothesis

The Environmental Kuznets Curve (EKC) hypothesis was first proposed by Grossman and Krueger in 1991 in their paper analyzing the relationship between sulfur dioxide concentration and per capita GDP in North American countries [11]. After that, several papers explained the reasons and mechanisms of the impact of economic growth on environmental degradation.

Environmental Kuznets Curve Hypothesis suggests that at the early stage of economic development, environmental degradation increases with economic growth; after a certain threshold, which is the turning point of the curve, environmental quality will improve with economic growth. This kind of relationship between environmental quality degradation and economic development is an inverted-U shaped curve.

Proximate causes of the inverted-U shaped relationship include scale of the economy, changes in economic structure, and improvement in technology, as summarized by Stern in 2004 [21]. Other forces like policy regulation, education level and environmental awareness, international trade, and market mechanisms that can affect the relationship indirectly through these proximate variables.

- Economic growth aggravates environmental degradation through the scale changes, which is called scale effect [9]. The expanding scale and the increasing outputs will require more and more inputs, which means more wastes products are generated and more resources are consumed.

- Through changes in economic structure, economic growth can affect environmental quality positively. This channel is called composition effect[9]. As the economy grows, it will move from being agriculturally based to being industrially based, which will lead to industrial pollution. Then, as it reduces its pollution-intensive industries and gradually moves into a post-industrial economy it will put more emphasis on clean industries and service sectors. Vukina (1999) proved the composition effect by examining the data of water pollution caused by the manufacturing sector [26]. Environmental policies will force the process of moving from industrially based economy to post-industrial economy. The Abatement J Curve hypotheses suggested by Selden and Song states that at the beginning, few regulations would be applied; but after a certain stage, highly increased regulation will be employed, thanks to a series of changes caused by economic growth, such as environmental awareness and increased demand for better environmental quality [18].

- As technology improves with economic growth it can help mitigate environmental degradation. Dirty and unregulated technologies will be replaced by improved clean technologies, which is environmentally friendly and can help improve environmental quality. Technological improvement has two parts [21]: 1) productivity, as the amount of resources used to produce one unit of output will decrease; 2) emission changes, as the amount of pollution emitted per unit of output will also decrease.

- The Pollutant Heaven hypothesis asserts that trade will improve the income level of people in developing countries and that this will increase the demand for higher environmental quality[1]. However, trade might also hurt the environment of developing countries, especially countries with weaker regulations and lower environmental standard, by moving pollution-intensive industries into them. Suri and Chapman (1998) demonstrated the impact of trade on the Kuznets Curve from an empirical perspective [23]. Cole (2004) also proved that the inverted-U shape of the Environmental Kuznets Curve can be explained by the migration of dirty industries from developed regions to developing regions [4].

- The market becomes complete with economic growth, and thus assigns efficient prices to resources and energies. At the early stages of economic growth, prices of natural resources are estimated lower than they are when heavy exploitation of resources has caused severe environmental degradation. As these resources are exploited and become rarer, their market prices will increases. Furthermore, these higher prices also contribute to the shift from resource-intensive industries to clean industries and the service sector, which will cause the composition effect [25].

Empirical Studies on Air Quality Degradation and Economic Growth

Most of the previous empirical studies concentrate on proving the inverted-U shaped relationship between economic growth and air quality degradation and on forecasting the turning-point (peak point) of the Kuznets Curve. Through econometric analysis, Although concluding with an inverted-U shaped relationship, as expected, these studies reported different turning points, varying from around \$3,000 of per capita income to around \$10,000 for cities and from \$8,000 of per capita GDP to more than \$100,000 for countries. However, few studies concentrate on the marginal effect of economic growth or industrial activities on air quality degradation are different.

Studies that focus on pollutant emission amounts agree that the inverted-U shaped relationship exists between per capita GDP (or per capita income) and pollutant emissions. Panayotou (1993) [15] used data for 68 countries and tested the curve for several air pollutants including SO_2, NO_X, and SPM. That study found that at an lower income level (\$300 per capita), a 1 percent increase in income per capita results in a 2.3 percent increase in emissions. And as income rises, the emissions elasticity declines, reaching zero at about \$3,000 per capita.

Selden and Song (1993) examined data for SO_2, NO_X, SPM, and CO covering 30 countries from 1974 to 1989. The estimated turning point of SO_2 and SPM were approximately \$10,000 of per capita GDP, while the turning point of NO_X and CO tended to be higher, around \$20,000. Cole (2004)[4] got similar results as Selden and Song. Cole used data for 18 countries and concluded that the turning point for SO_2 was around \$7,000 per capita income ,for NO_X was around \$17,000, and for CO was around \$24,000 per capita income.

List (1999) [14] got opposite results and suggested that the turning point of NO*X* was around \$10,000 per capita income and the SO_2 curve had a turning point at approximately \$20,000. Their study used data for the U.S. from 1929 to 1994. There are also studies that concluded with even larger turning points. Stern (2001) [22] examined SO_2 emission data for 73 countries from 1960 to 1990 and suggested a turning point at around \$101,166 per capita GDP.

Relatively fewer studies are using pollutant concentration values as their dependent variable. Grossman (1991) [11] examined up to 52 cities in 42 countries and examined the Kuznets Curve for SO_2 concentration and SPM concentration. The turning point of the curves are estimated at around $5,000 per capita GDP. Panayotou (1997) [16] used data for cities in 30 countries from 1982 to 1994 and concluded with similar results: turning points around $ 5,000 per capita GDP for SO_2 concentration. Both studies included regions in developing countries and developed countries. A country-level study on SO_2 concentrations conducted by Kaufmann, Davidsdottir, Garnham, and Pauly (1998) suggests a larger turning point — around 14,000 dollars of per capita GDP [13]. This study included 13 developed countries and 10 developing countries and covered 1974 to 1989.

Several studies look into firms' productivity and investigate the relationship between firm output and environmental quality. They found that larger firms have lower emissions intensities (Cole et al., 2013), and exporters tend to have fewer emissions relative to non-exporters (Forslid et al., 2011). Cole (2014) develop a theoretical model of international environmental outsourcing , use a firm-level dataset for Japan, and do find evidence of an environmental outsourcing effect [6].

Studies of China have produced various results in both the relationship of economic growth to air quality and the turning point. Among studies at the provincial level, De Groot, Withagen, and Zhou [8] addressed the existence of an EKC for China using a sample of 30 regions, covering the period from 1982 to1997. They indicated that the increase in industrial solid and gas emissions tends to decelerate at intermediate levels of Gross Regional Product (GRP) per capita, but accelerates again at high levels of GRP per capita, according to the cubic model. Song (2008) [24] investigated the relationship between pollution and economic growth in China across 29 provinces from 1985 to 2005. The turning point of industrial emission curve was estimated at around 29,000 RMB per capita GDP. Shen (2006) [20] examined data for 31 provinces in China from 1993 to 2002. The study found that the variation of dust fall emissions with respect to per capita GDP follows the Environmental Kuznets Curve, while the SO_2 emissions tend to decrease at a smaller value of per capita GDP and then increase after per capita GDP researches the turning point, which is opposite from the Environmental Kuznets Curve Hypothesis.

Fewer studies have been done at the city level. He (2012) [12] compiled data from 74 cities in China from 1990 to 2001 and assessed the relationship between economic growth, economic structure, development policy, and air quality. This study chose SO_2 concentration, NO_X concentration and TSP concentration as the dependent variables and found inverted -U shaped relationships for the TSP curve and the NO_X curve and a U-shaped relationship for the SO_2 curve.

CHAPTER 2

DATA

This analysis is performed on a merged database of Air Quality Index (AQI) and economic and demographic data from 2000 to 2012. The panel database covers 118 cities, the locations of which are shown in Figure 2.1. Starting in 2000 when 45 cities made public their air quality index data for the first time, cities in China successively released their air quality data. AQI data from 120 cities are available by the end of 2012.[1] The unbalanced database includes 1,050 observations in total, with the number of observations in each year varying from 45 to 118, as shown in Table 2.1.

Table 2.1: Summary of the Unbalance Panel (Number of Cities in each Year)

Year	2000	2001	2002	2003	2004	2005	2006
Number of Obs.	41	45	70	70	82	86	84
Year	2007	2008	2009	2010	2011	2012	
Number of Obs.	84	84	84	84	118	118	

2.1 Air Quality Data

The dependent variable, AQI, is an index for reporting daily air quality by combining the concentrations of SO_2, NO_x, CO, O_3 $PM_{2.5}$ and PM_{10} together. The range of AQI values is defined from 0 to 500. According to the document published by the Chinese government ([17]), *AQI and Health Implications (HJ 663-2012)*, AQI values less than 50 indicate that the air quality of a city does not

[1]Two of these 120 cities' economic data are not available. The panel includes 118 cities in total. Economic data for two of the 120 cities are not available, so the panel shows 118 cities in all.

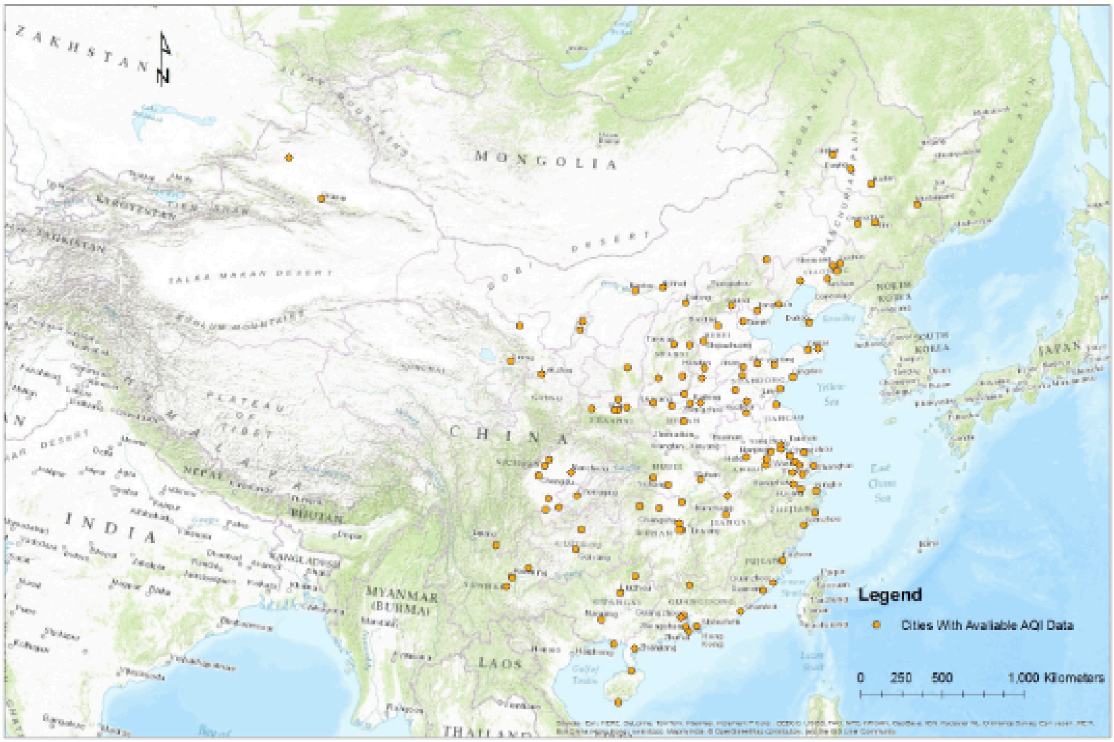
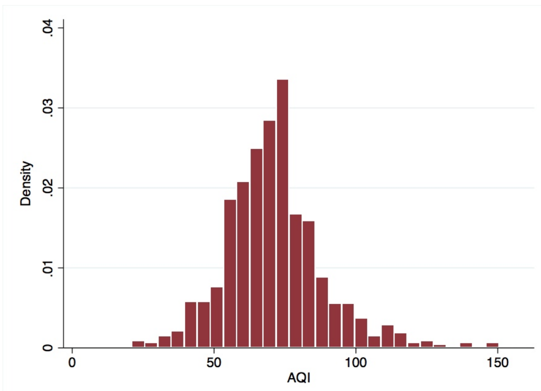


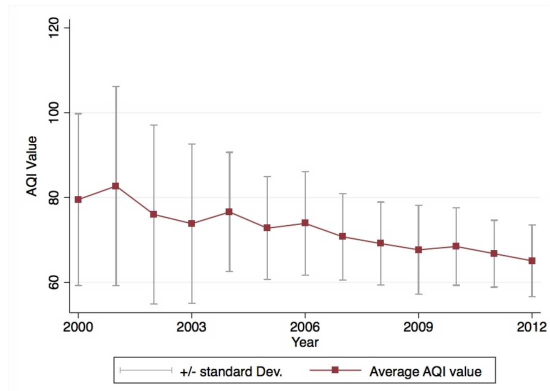
Figure 2.1: Location of the 118 Cities

have health implications, while AQI values larger than 200 will have a noticeably effect on human health. The definition of AQI and further explanation of the index are shown in Appendix A.

There are several advantages to using AQI as the dependent variable, instead of emissions, which were commonly used in the literature previously. First, AQI can suggest the status of the atmosphere better than emissions can. After being emitted into the atmosphere, pollutants are transported, dispersed, or deposited. The atmosphere can self-clean some of these pollutants; therefore, the actual level of air quality degradation cannot be simply represented by the level of emissions. For this reason, research that focuses on pollutant concentrations is needed to further support the results of emissions studies and to make a convincing argument for the impact of human economic activities on environmental degradation. Second, unlike measurements of the concentration of a single pollutant, AQI is a comprehensive indicator that includes most crucial pollutants. As explained in the first section, China suffers from several severe pollutants and their collective behavior further worsens the situation. Therefore, AQI is the best measure to test the consequences of economic activities on air quality degradation. For these reasons, this research uses AQI as a dependent variable. Statistics of AQI is shown in Figure 2.2 and Table 2.2.



(a) Distribution of AQI



(b) Variation of AQI across years

Figure 2.2: Statistics of AQI

Air quality changes from year to year, it changes with weather conditions, and it varies by geographic location. Figure 2.3 uses air quality in 2012 as an example to depict AQI values across geographic locations.

AQI values of coastal cities are lower than other cities, especially cities in the southeast of China. Latitude also influences air qualities. Cities in North China have more serious air quality problems. As latitude increases, the value of AQI increases.

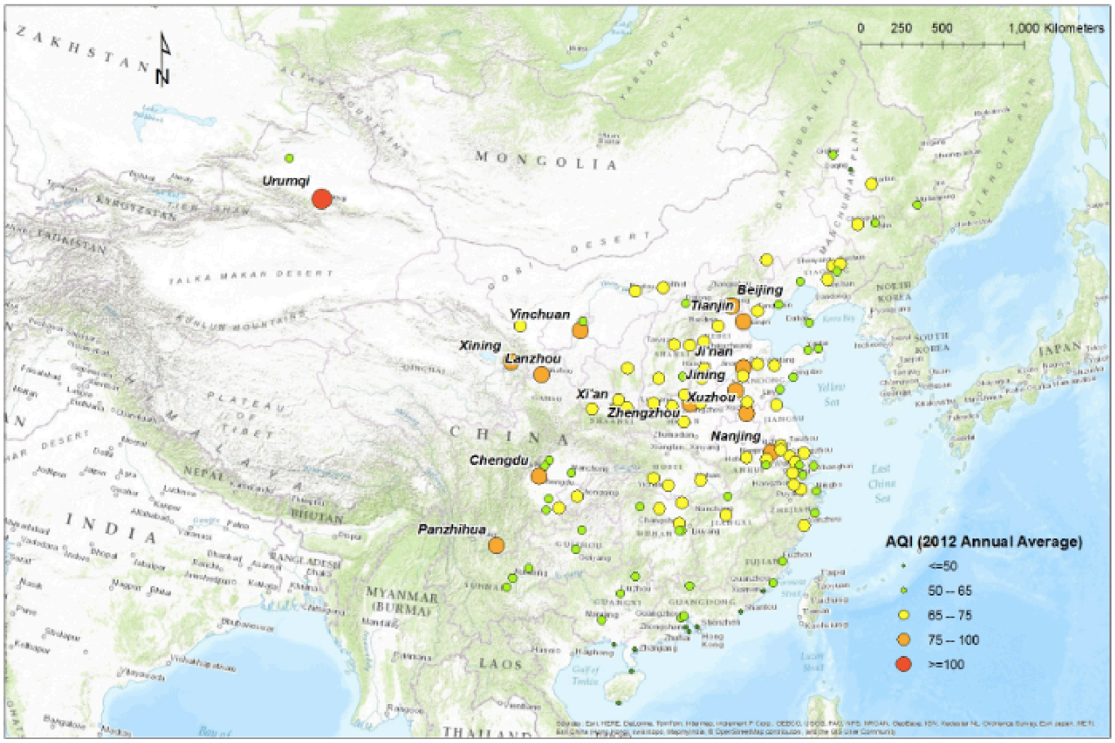


Figure 2.3: Variation of AQI across geographic conditions (2012)

2.2 Economic Data

This research measures economic performance and industrial activities in GDP per area and industrial output. Economic and demographic variables come from China Data Online, a database that contains statistical data for most cities in China. The industries in this project are all classified as either pollution-intensive industries or non-pollution-intensive industries. Statistics of the main independent variables are listed in Table 2.2. Appendix A has further explanations of the dataset, the list of available industries, and the definition of pollution-intensive industries.

Here we used GDP per area (or industrial output per area) as the explanatory variable. Estimates of GDP per capita as alternative independent variables are in Appendix B.2.

2.3 Descriptive Statistics

The statistics for the variables used in our estimates are reported in Table 2.2. To assess the impact of economic growth on air quality, this research uses AQI as the dependent variable and uses GDP per area and industrial output as the independent variables. This study investigates the impacts of pollution-intensive industries and non-pollution-intensive industries separately and tests to what extent the impact of pollution-intensive industries is higher than non-pollution-intensive industries.

Controlled variables include cities geographic properties (longitude and latitude, coastal location or in-land), demographic properties (area and population density), and pollution regulation policies (taxes). The demographic data and economic data are from China Data Online. The tax variables are self-collated from the provinces environmental pollution regulation documents.

Table 2.2: Sample Statistics

Var.	Explanation	Units	Obs.	Mean	Std.Dev.	Min	Max
Dependent Var.							
AQI	Annual average of daily AQI	–	1050	71.386	17.610	21.041	159.802
Explanatory Var.							
GDPperA	Per area GDP	10 million yuan/sq.km	1050	2.466	4.709	.032	62.319
Sec.GDPperA	Per area Secondary Industry GDP	10 million yuan/sq.km	1050	1.227	2.235	.014	27.614
PI-OutputPerA	Per area output of pollution-intensive industries	10 million yuan/sq.km	960	1.266	1.596	.003	11.196
Non-PI-OutputPerA	Per area output of non-pollution-intensive industries	10 million yuan/sq.km	960	1.341	2.357	.002	19.851
Controlled Var.							
Coastal city	Dummy (costal = 1, inland = 0)	–	1050	.288	.453	0	1
Latitude	Latitude of the city	Degree (N)	1050	32.900	6.659	18.25	47.6
Longitude	Longitude of the city	Degree (E)	1050	114.123	7.455	84.55	131.12
Area	Total land Area of the city	10000 sq.km	1050	1.254	1.122	.024	9.066
PopDens	Population Density at year-end	100 persons per sq.km	1050	5.671	4.786	.265	56.949
Tax	SO_2 Pollution tax of each province	Yuan /kg	1050	.632	.336	.04	1.26

Note: All the variables measured by monetary values are converted into 1999 price of RMB. All the variables (excluding "Tax") are at city-level. The variable "Tax" is at province level because the pollution tax policies are made by province government and are implemented uniformly within each province. Data for industry outputs are missing for year 2011 (Details are explained in appendix).
Data Source: China Data Online; Ministry of Environmental Protection of the People's Republic of China; China National Knowledge Infrastructure.

To show these variables across time, Table 2.3 compares the sample means of main variables in 2000, 2002, 2005, 2008, and 2012. These summary statistics are for the subsample of 41 cities for which AQI values have been available since 2000. Using these 41 cities instead of the full sample avoids endogenous changes driven by the increasing sample size across years. According to Table 2.3, the AQI value decreases by about 15 between 2000 and 2012. During these 13 years, the values of the AQI seem to have increased in the first several years. In 2002, the annual average daily AQI is 2.4 higher than in 2000. And in 2012, the annual average daily AQI is 65.9, which is 13.6 lower than in 2000. However, the value is still too high for human health.

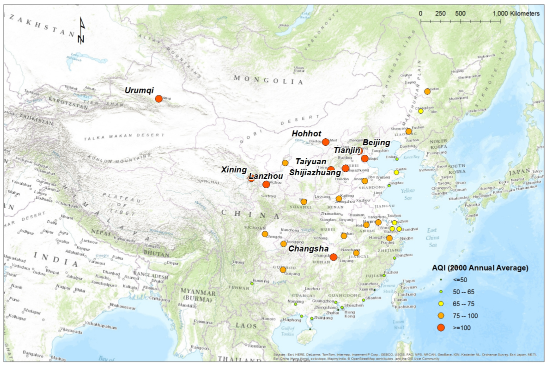
Figure 2.4 shows the AQI pattern of the full sample over the selected 5 years, which indicates a decreasing trend as well. On the maps, red spots stand for cities whose annual average AQIs are higher than 100, which indicates seriously polluted areas. These cities are labeled by name. Figure 2.4 and Table 2.3 together suggest that the decreasing trend of AQI is not driven by the changing sample cities over the years.

The economic trend of China between 2000 and 2012 is one of rapid growth. According to a preliminary view of the data patterns, the inverted-U shape trend of AQI and increasing trend of GDP aligns with previous studies results: Economic growth will at first aggravate the environment and then promote environmental protection and consequently help to mitigate the environmental degradation after a certain stage.

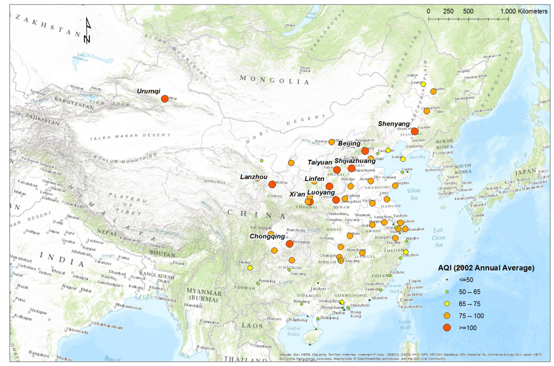
Table 2.3: Trends in Air Quality and GDP in China, 2000 - 2012

Var.	2000	2002	2005	2008	2012
Dependent Var.					
AQI	79.524	81.892	72.523	70.169	65.919
Explanatory Var.					
GDPperA	1.367	1.734	2.676	4.131	7.198
Sec.GDPperA	0.626	0.807	1.316	1.982	3.254
PI-OutputPerA	0.623	0.735	1.563	2.564	4.066
Non-PI-OutputPerA	0.904	1.310	2.753	4.517	6.963

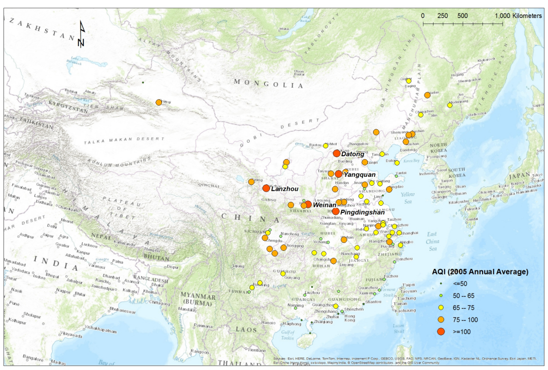
Unit of GDPperA and Sec.GDPperA : 10 million Yuan/sq,km. Data Source: China Data Online. This statistics includes the 41 cities where AQI data are available since 2000 only. This descriptive statistics show the trends roughly: while the economics is keep growing, the AQI tends to increase at first and then starts decreasing. Using the 41 cities instead of the full sample avoids endogenous changes driven by the increasing sample size across years.



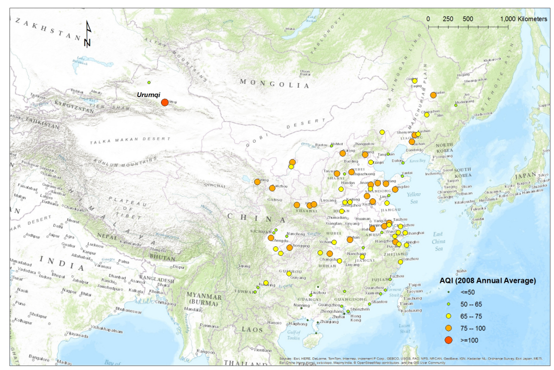
(a) 2000



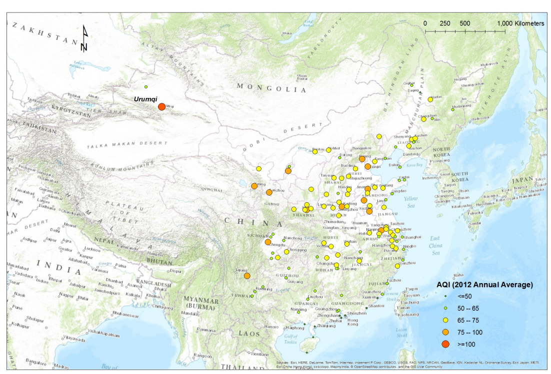
(b) 2002



(c) 2005



(d) 2008



(e) 2012

Figure 2.4: Variations of city-level annual average AQI across time

CHAPTER 3

EMPIRICAL STRATEGIES

As explained in Chapter 1, it is well known that in China both economic growth and air quality degradation are accelerating at rates that are unique. Although there is evidence and there are theories to suggest the relationship between economic growth and air quality, this paper seeks to quantify the precise impact of economic growth on air quality in the context of China and similar developing areas.

First, this study estimates the impact of increasing GDP per area on AQI using 118 Chinese cities. Based on the estimated impact, this study then predicts how the air quality would response to continuous economic growth in China. If Chinas GDP remains at approximately 7% each year as expected under President Xis new normal economic development, how will air quality change correspondingly? If the "One Belt, One Road" project lead to more investment in western China, how will air quality be influenced?

Second, this study estimates the impact of activities of different industries and tests the difference in the impacts of pollution-intensive industries and non-pollution-intensive industries.

To identify the impact, this study constructs instrumental variables to deal with the endogeneity in the relationship between economic activities and air quality. It then uses the Two Stage Least Squares (2SLS) model to identify the impacts.

3.1 Basic Econometric Model

Following the conventional model that was used in most studies, the main model in this study is specified as:

$$AQI_{i,t} = \beta_1 Y_{i,t} + \beta_2 Y_{i,t}^2 + \boldsymbol{\beta}_k Controls_{i,t} + \alpha_1 Time_t + \alpha_2 City_i + \varepsilon_{i,t}$$

i : Index of cities, 1-118

t : Index of year, 1 - 13

The explanatory variable $Y_{i,t}$ is GDP per area, secondary sector GDP per area, or industrial outputs per area. I test both the linear and quadratic models and test the estimation results using different specifications.

Control variables include a citys population density, the citys area, and the provincial-level pollution tax rate. Although number of vehicles are also useful controlled variables that correlate with air quality, these two variables are excluded from the main model because their data quality is low. We think that nearly 10% of vehicle population values are missing in our data set. If we include these controlled variables it will shrink the sample size. Also including these controls does not lead to significant changes in the estimation results.

3.2 Identification

3.2.1 Sources of Endogeneity

Intuitively, we know that the term GDP per area (or industrial output per area) in this model has endogeneity problems because GDP or industrial output is a complex value correlated with several factors. It is highly probable to have a omitted variable problem and consequently an endogenous relationship in this model.

Macroeconomic policies, Five Year Plans, and environmental quality control policies might be are related to each other. Policymakers are aware that the development of the economy might cause environmental degradation. If a city or province faces severe air pollution, then policymakers might choose to restrict the development of local pollution-intensive industries. This policy might lead to a decrease in both the dependent variable AQI and the independent variable GDP or industrial output.

Furthermore, variables in emission sources other than industries, such as transportation, are not included in the model due to a lack of data. All of these omitted factors, which are absorbed by the error term, are correlated with GDP, industrial outputs as well as AQI.

In addition, the endogenous issue in estimating the impact of industry output growth on AQI is more serious than estimating the impact of economic growth. As summarized in Section 1.2, economic growth influences air quality through several variables and channels, including regulation policy, education level, growth of industry output, improvement of technologies. Therefore, to estimate the effect of economic growth on air quality degradation, these channels and variables should not be controlled. These variables should be allowed to vary in the estimation model. Otherwise, the effect of economic growth on air quality changes will be restricted to one or several certain channels. Instead, while estimating the effect of the growth of industrial output, which is a certain channel, other uncertain channels and related variables, such as education level and policies, should be controlled. However, these variables are not available.

3.2.2 Instrumental Variable Construction

To find the exogenous part of economic growth, this study use economic status of foreign countries as instrumental variables (IV) for the economic development status of Chinese cities. Thanks to the increasing globalization of the past several decades, most cities in China have trade with foreign countries. Because secondary industry produces major exported commodities, the economic status of the export destination countries can represent the economic vitality of Chinese cities, especially the vitality of the secondary sector. Intuitively, this study believes that functions of foreign countries economic conditions are able to explain the variation of the exogenous part of the term secondary industry GDP per area in the model.

Foreign countries influence the economic status of Chinese cities by importing commodities from China. Thus, to a large extent, IVs for the GDP of Chinese cities (especially secondary industry GDP) can be constructed from the economic conditions of its top several export destination countries.

Generally, economic conditions of a country can be represented by GDP. In this study, because the link between instrumental variables and independent variables is international trade, it is also important to consider the import value of the destination countries as an alternative instrumental variable. To make the IVs feasible and easily constructed, only the top five destination countries are selected for each city. The share of total export value that comes from the top five destination countries indicates that considering five countries is enough.

The minimum share value is 71% and the maximum share value is 100%.

Therefore, this study uses a weighted summation of the top five destination countries GDP as the instrumental variable for per area secondary industry GDP of each city. The weights are the share of goods exported from city i to destination country j to the total exports of that city i. The formulas are shown below:

Therefore, this study uses a weighted summation of the top five destination countries GDP as the instrumental variable for secondary sector GDP per area of each city. The weights are the share of goods exported from city *i* to destination country *j* to the total exports of that city *i*. The formulas are shown below:

$$Weighted.GDP_{i,t} = \sum_{j=1}^{5} NormalizedExportShare_{i,j,2000} \times GDP_{j,t}$$

$$NormalizedExportShare_{i,j,2000} = \frac{ExportShare_{i,j,2000}}{\sum_{i=1}^{5} ExportShare_{i,j,2000}}$$

$$ExportShare_{i,j,2000} = \frac{Export_{\text{from i to j,2000}}}{TotalExport_{i,2000}}$$

i :Index of cities, 1-118

t :Index of year, 2001 - 2012

j :Index of destination countries, 1 - 5,

Note that the five selected destination countries are different for different cities. Because the sum of the top five countries export values for a city might not equal one and varies across time, the export share values should be normalized, as shown in the second and third equations above. Instead of using the export values of the current year, this study uses the export share of year 2000 as the weight of the summation and drops the 41 observations in 2000 from the analysis. The value of the export share in 2000 will not influence air quality from 2001 to 2012 directly. The summation $Weighted.GDP_{i,t}$ are constructed exogenous from 2001 to 2012.

Considering that different cities have different export intensities and rely on foreign countries differently, export intensity (denoted EI in the equations) for each city in 2000 are included while constructing IVs. We add the interaction of export intensity and the weighted summation of GDP shown in the formulas above as the second instrumental variable.

Furthermore, since the suspended endogenous variable is per area secondary industry GDP, the IVs are divided by the area of the cities. The two IVs for the explanatory variable secondary sector GDP per area are:

$$IV_{i,t} = [Weighted.GDP_{i,t}/Area_i\ ,\ EI_{i,2000} \times Weighted.GDP_{i,t}/Area_i]$$

i : Index of cities, 1-118

t : Index of year, 1-12

As explained above, alternative IVs are constructed by substituting GDP of the destination countries for the amount of goods imported to the destination countries. Tests made with alternative IVs are included in Appendix B.1. The estimation results are similar to the main model but have weaker first-stage results. Figure 3.1 depicts the unconditional trends of AQI, per area GDP, and IVs over time.

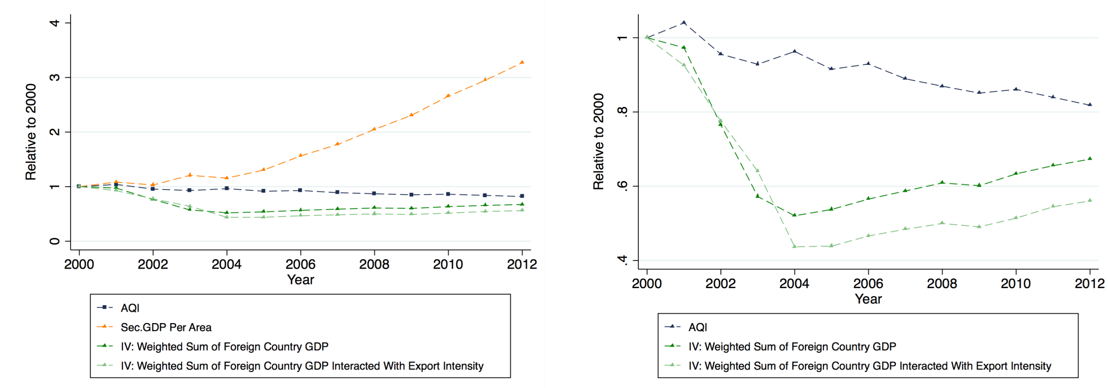
3.2.3 Statistics on Instrumental Variables and Independent Variables

Overall, the first-stage result reports a cluster-robust F-statistic larger than 10. As shown in Table 3.1, the use of foreign countries GDPs to construct IVs leads to stronger first-stage results. Therefore, this paper uses weighted sums of trading partners GDPs as IVs for GDP or industrial outputs of Chinese cities. Tests of the use of alternative IVs to estimate the impact of economic growth on air quality are included in Appendix B.1. The estimate results are similar to the main model but with weaker first-stage results.

Table 3.1: Results of First Stage Regressions

	(1) Sec.GDPperA	(2) Sec.GDPperA
IV: $Weighted.GDP_{i,t}/Area_i$	-0.0117	
	(0.0957)	
IV: $EI_{i,2000} \times Weighted.GDP_{i,t}/Area_i$	10.8748**	
	(4.5504)	
IV: $Weighted.Import_{i,t}/Area_i$		0.0034
		(0.049)
IV: $EI_{i,2000} \times Weighted.Import_{i,t}/Area_i$		3.3486*
		(1.7663)
Controls	Yes	Yes
Year FE	Yes	Yes
City FE	Yes	Yes
N	1009	1009
$adj.R^2$	0.664	0.627
F(2,117) =	18.67	10.88
Prob.>F =	0.0000	0.0000

Standard errors are adjusted for 118 clusters in city. Significance levels are indicated by * p<0.10, ** p<0.05, *** p<0.01 According to the F test, the IVs are strong and valid for "Sec.GDPperA" and its square term.



(a) Independent variable and IVs

(b) Dependent variable and IVs

Figure 3.1: Variations of IVs and the dependent variable across years

CHAPTER 4

ESTIMATION RESULTS

The analysis starts by testing the relationship between GDP per area and air quality. The result is consistent with the previous literature: At the first stage, economic growth is associated with air quality degradation; after a turning point economic growth benefits air quality.

This study then uses the economic activities of export destination countries as instrumental variables for secondary industry growth to estimate the impact of per area secondary industry GDP on air quality. The results suggest a quadratic relationship between economic growth and air quality degradation, but the estimated marginal impact is stronger than results from most previous studies: a 10% increase in pollution-intensive industry output is associated with a 5% increase in air pollutant concentrations, on average.

Furthermore, this study separates the secondary sector into pollution-intensive industries and non-pollution-intensive industries and finds that the negative impact of secondary industry growth on air quality is mostly driven by the pollution-intensive industries. This study finds a significant linear relationship between pollution-intensive industry outputs and AQI. The marginal effect of pollution-intensive industry outputs is more than 3 times higher than non-pollution-intensive industry.

4.1 Impact of Economic Growth on Air quality

Table 4.1 shows the results of regressing AQI against GDP per area and a series of controlled variables. Columns 2, 3, 5, and 6 include city fixed effects to control for time-invariant unobservables. In columns 1, 3, 4, and 6, year fixed effects are included to control for nationwide shocks. In columns 2 and 5, city-specific year trends are included to control for trends in economic development and air quality changes.

The results in the first three columns suggest that the impact of economic growth on air quality degradation is positive, on average. However, this impact is not significant. The last three columns suggest that the relationship between economic growth and AQI is quadratic. The results are robust to different specifications.

These results are consistent with previous studies. The derivative of AQI with respect to GDP depends on the stage of the economy: At first, the derivative is positive; after the turning point, the derivative becomes negative. The marginal effect decreases as per area GDP increases. The regression result suggests that the turning point is approximately 361.9 billion yuan per sq. km of per area GDP. In the sample, although the highest value of per area GDP is 620 billion yuan per sq. km, most of the observations fall in the interval in which per area GDP is smaller than 361.9 billion yuan per sq. km. Only the city of Shenzhen is on the right side of the turning point. Thus, a quadratic relationship is actually an increasing trend for observations in the sample. Figure 4.1 represents the in-sample fitted value and the out-of-sample prediction of air quality degradation.

List and Gallet (1999) [14] also found that the turning point is on the boundary of the sample in his research on SO_2 emissions in the United States. Song, Zheng, and Tong (2008) [24] studied on industrial emissions in China and found that although the relationship is an inverted-U shaped curve, all of the observations in the sample are on the increasing part of the curve (left side).

Table 4.1: Relationship between AQI and per area GDP

	(1)	(2)	(3)	(4)	(5)	(6)
	AQI	AQI	AQI	AQI	AQI	AQI
GDPperArea	0.2011	0.2472	0.2237	0.7310**	0.9335*	0.9122*
	(0.1360)	(0.1740)	(0.1656)	(0.3305)	(0.4996)	(0.4678)
GDPperArea^2				-0.0104**	-0.0125*	-0.0126**
				(0.0047)	(0.0068)	(0.0063)
SO_2 Tax	7.4405***	6.3735**	8.3208**	6.1019**	5.8968**	8.0459**
	(2.8586)	(2.8907)	(3.1956)	(2.8723)	(3.1010)	(3.2069)
PopDens	-0.0048	-0.0062	-0.0060	-0.0054	-0.0064	-0.0063
	(0.0044)	(0.0043)	(0.0045)	(0.0051)	(0.0054)	(0.0052)
Area	-0.6481	6.3886**	7.8418***	-0.3105	7.9186***	9.2253***
	(0.6689)	(2.5137)	(2.9032)	(0.7078)	(2.9598))	(3.2022)
Longitude	-0.2903			-0.3362		
	(0.3071)			(0.3176)		
Latitude	1.0701***			1.0997***		
	(0.2749)			(0.2798)		
Coastal	-11.0394***			-11.2761***		
	(2.9841)			(2.9993)		
Year FE	Yes		Yes	Yes		Yes
City-Specific Year Trend		Yes			Yes	
City FE		Yes	Yes		Yes	Yes
N	1050	1050	1050	1050	1050	1050
$adj.R^2$	-	0.209	0.226	-	-	0.231

Unit of GDPperArea: 10 million yuan/sq.km. City fixed effects are included in Column 2, 3, 5, and 6. Year fixed effects are included in Column 1, 3, 4, and 6. City-specific year trend are included in Column 2 and 5. Standard errors (shown in parentheses) are clustered at the city level. Significance levels are indicated by * p<0.10, ** p<0.05, *** p<0.01.

The results suggest that at the mean value of per area GDP in the sample (25 million yuan/sq. km), a one standard deviation increase (47.8) in per area GDP is associated with an increase of 3.7 in AQI.

Although this estimation shows the relationship between economic growth

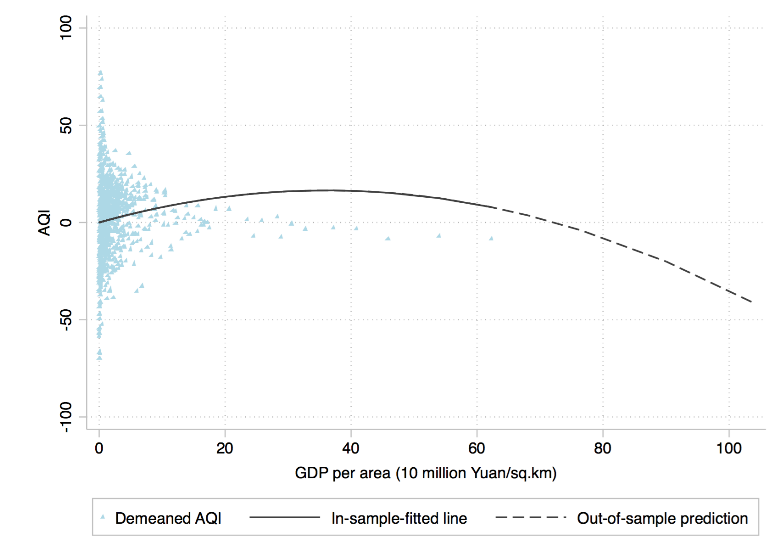


Figure 4.1: Relationship between per area GDP and AQI

and air quality, it cannot represent the impact of economic growth on air quality in China because the relationship between GDP and AQI is endogenous, as explained in Chapter 3.2.1. Chapter 4.2 will report the results of using instrumental variables to estimate the impact of secondary industry GDP on air quality.

4.2 Impact of the Secondary Industry on Air quality

The first 2 columns in table 4.2 summarizes the OLS regression results of the impact of secondary industry GDP per area on air quality. The results suggest a quadratic relationship. If the per area secondary industry GDP is smaller than 176.1 million Yuan/sq.km, an increase in GDP is associated with an increase in AQI. Only 5 cities in the sample have secondary industry GDP values larger than 176.1 million Yuan/sq.km. At the mean value of secondary industry GDP per area (12 million yuan/sq.km), a 1 million yuan/sq.km increase is associated with an increase of 2.1 in AQI.

Table 4.2: Relationship between AQI and per area Secondary Industry GDP

	Results from OLS		Results from IV (2SLS)	
	(1)	(2)	(3)	(4)
	AQI	AQI	AQI	AQI
Sec.GDPperArea	0.6367	2.1946**	1.0193	6.4320***
	(0.4608)	(1.0900)	(0.8434)	(2.1822)
Sec.GDPperArea^2		-0.0623**		-0.1876***
		(0.0306)		(0.0656)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
N	1009	1009	1009	1009
$adj.R^2$	0.236	0.241	0.131	0.097

Unit of secondary industry GDP per area: 10 million yuan/sq.km. Year fixed effects and city fixed effects are included in all the regressions. Observations in 2000 are dropped in all the regressions to keep the IVs exogenous. (Further explanation are in Chapter 3.2.2.) To keep results in this table comparable, observations in 2000 are dropped in OLS estimations as well. First stages results of column (3) and (4) are shown in Table 4.3. Standard errors (shown in parentheses) are clustered at the city level. Significance levels are indicated by * p<0.10, ** p<0.05, *** p<0.01.

To address the potential endogeneity due to unobservables, we instrumentalize secondary industry GDP per area using the economic status of foreign countries, as discussed in Chapter 3.2.2. The last 2 columns in table 4.2 report the results from IV regressions.The first-stage results of the 2SLS regressions are reported in Table 4.3. The F-test on the IVs suggests a strong first-stage result.

Compared with the results from OLS in Table 3, the estimated impacts of the IV regressions are considerably larger. Figure 4.2 visualizes the quadratic relationship. The gray line is the estimated relationship from the OLS model (Column 2 in Table 4.2) and the black line shows the estimated relationship from the 2SLS model (Column 4 in Table 4.2). The difference in the derivative of the two curves is large.

Table 4.3: First Stage of the 2SLS regression in Table 4.2

	(1)	(2)	
	Linear Model	Quadratic Model	
	Sec.GDPperArea	Sec.GDPperArea	Sec.GDPperArea^2
IV: $Weighted.GDP_{i,t}/Area_i$	-0.0117	0.2825**	5.5481***
	(0.0957)	(0.1184)	(1.7593)
IV: $(Weighted.GDP_{i,t}/Area_i)^2$		-0.0007	-0.0240
		(0.0008)	(0.0199)
IV: $EI_{i,2000} \times Weighted.GDP_{i,t}/Area_i$	10.8748**	-13.9649***	-540.2871***
	(4.5504)	(4.6825)	(130.8939)
IV: $(EI_{i,2000} \times Weighted.GDP_{i,t}/Area_i)^2$		4.0544***	154.5372***
		(0.5406)	(17.5796)
Controls	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
City FE	Yes	Yes	Yes
N	1009	1009	1009
$adj.R^2$	0.664	0.777	0.837
F-test of excluded instruments:			
F(2,117) or F(4,117)=	18.67	597.58	256.70
Prob.>F =	0.0000	0.0000	0.0000
Sanderson-Windmeijer multivariate F-test of excluded instruments:			
F(2,117) or F(4,117) =	18.67	84.99	81.67
Prob.>F =	0.0000	0.0000	0.0000

Standard errors (shown in parentheses) are clustered at the city level. Significance levels are indicated by * p<0.10, ** p<0.05, *** p<0.01. According to the F test, the IVs are strong and valid for "Sec.GDPperA" and its square term.

According to the results from 2SLS regression, if the per area secondary industry GDP is smaller than 171.4 million yuan/sq. km, then an increase in GDP is associated with an increase in AQI. At the mean value of per area secondary industry GDP (12 million yuan/sq. km), a 1 million yuan/sq. km increase is associated with an increase of 5.9 in AQI, which is about twice as big as the OLS estimated impact.

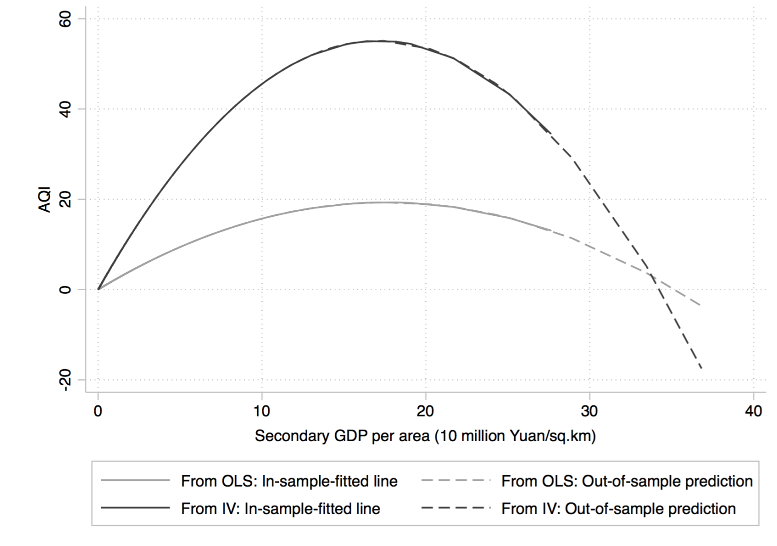


Figure 4.2: Relationship between per area Secondary Industry GDP and AQI

4.3 Impact of Pollution-Intensive Industries And Non-Pollution-Intensive Industries

Table 4.4 represents the results of an OLS regression of AQI with respect to the output of pollution- intensive industries and non-pollution-intensive industries output from OLS. The results suggest that, on average, an increase in pollution-intensive industries is associated with an increase in AQI. But the relationship is not significant. I suspect it is due to the an endogenous problem.

To address the potential of an endogenous problem, Table 4.5 reports the results from 2SLS. Instead of using the total export values of the a city, IVs in this section are constructed using from the export values of pollution-intensive industries and non-pollution-intensive industries, respectively.

Table 4.4: Relationship between AQI and per area Pollution-Intensive Industry Output (from OLS)

	(1) AQI	(2) AQI	(3) AQI	(4) AQI
Pollution-Intensive OutputPerArea	0.8132	1.2860		
	(0.5015)	(1.2939)		
Pollution-Intensive OutputPerArea^2		-0.0331		
		(0.0686)		
Non-Pollution-Intensive OutputPerArea			0.2153	0.8223**
			(0.1390)	(0.3488)
Non-Pollution-Intensive OutputPerArea^2				-0.0082**
				(0.0035)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
N	919	919	919	919
$adj.R^2$	0.235	0.235	0.233	0.240

Unit of OutputPerArea: 10 million yuan/sq.km. Standard errors (shown in parentheses) are clustered at the city level. Significance levels are indicated by * p<0.10, ** p<0.05, *** p<0.01.

As expected, the estimated impact from pollution-intensive industries is much larger than from non-pollution-intensive industries. According to our estimate, if pollution-intensive industrial output increases by 10 million yuan/sq. km, AQI of a city will increase 2.6 times. (The mean value of AQI is 71.4.) Non-pollution-intensive industry output and air quality degradation is positively correlated on average, but it is not significant.

Figure 4.3 As expected, the estimated impact from pollution-intensive industries is much larger than from non-pollution-intensive industries. According to our estimate, if pollution-intensive industrial output increases by 10 million yuan/sq. km, AQI of a city will increase 2.6 times. (The mean value of AQI is 71.4.) Non-pollution-intensive industry output and air quality degradation is positively correlated on average, but it is not significant.

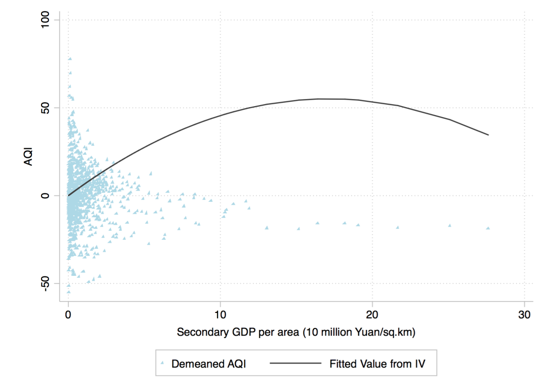
Table 4.5: Relationship between AQI and per area Pollution-Intensive Industry Output (from IV)

	(1) Pollution-Intensive		(2) Non-Pollution-Intensive	
	(1^{st})	(2^{nd})	(1^{st})	(2^{nd})
	Output/Area	AQI	Output/Area	AQI
Pollution-Intensive Output/Area		2.6828**		
		(1.3061)		
Non-Pollution-Intensive Output/Area				0.7504
				(0.4832)
IV: $Weighted.GDP_{i,t}/Area_i$	-0.0005		-0.5446**	
	(0.0021)		(0.2382)	
IV:[1] PI-$EI_{i,2000} \times Weighted.GDP_{i,t}/Area_i$	0.6447***			
	(0.0804)			
IV:[2] NPI-$EI_{i,2000} \times Weighted.GDP_{i,t}/Area_i$			4.3371**	
			(1.8427)	
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
N	919	919	919	919
$adj.R^2$	0.585	0.080	0.580	0.089

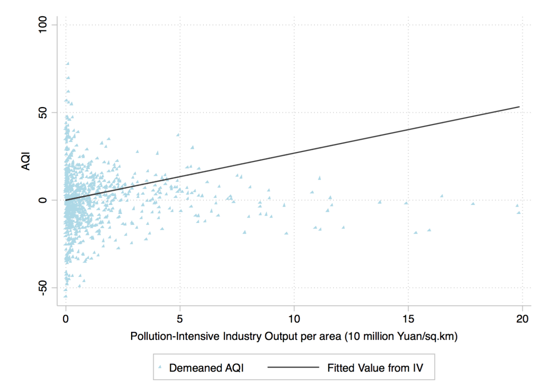
Unit of OutputPerArea: 10 million yuan/sq.km. F-tests suggest strong first stage for both regressions. Standard errors (shown in parentheses) are clustered at the city level. Significance levels are indicated by * p<0.10, ** p<0.05, *** p<0.01.

[1] PI-$EI_{i,2000} = \dfrac{\text{Export of All Pollution-Intensive Industries}_{i,2000}}{\text{Output of All Pollution-Intensive Industries}_{i,2000}}$, where i is city index.

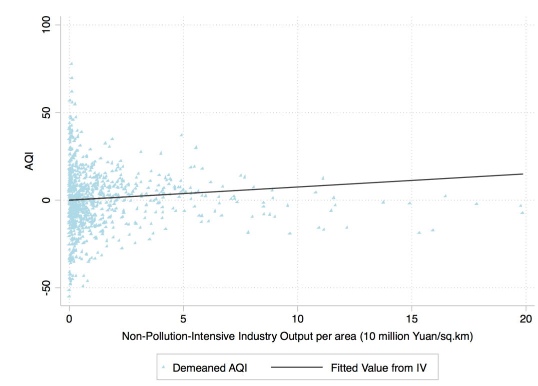
[2] NPI-$EI_{i,2000} = \dfrac{\text{Export of All Non-Pollution-Intensive Industries}_{i,2000}}{\text{Output of All Pollution-Intensive Industries}_{i,2000}}$, where i is city index.



(a) Impact of the secondary industry



(b) Impact of Pollution-Intensive Industries



(c) Impact of Non-Pollution-Intensive Industries)

Figure 4.3: Impact of pollution-intensive industries and non-pollution-intensive industries on air quality

CHAPTER 5

DISCUSSION

Like several previous studies, this study finds a quadratic relationship between economic growth and air quality. However, in contrast to those previous studies, this one finds a much larger turning point of economic growth and suggests in the current stage that an increase in GDP is associated with an increase in AQI. The turning points in previous studies were between $5,000 and 20$,000 per capita GDP. Regression results from this study suggest that the turning point is 361.9 million yuan/sq. km, or between $50,000 and 70$,000 dollars. It is a rare region that has reached that point. This indicates that economic growth and air quality are negatively associated for almost all cities. That might be because previous studies did not address the potential of an endogenous problem, and they underestimated the impact of economic growth on air quality degradation.

Based on the estimated impact, if the GDP per area of a city increases from the 75th percentile in our sample to the 99th percentile, then the annual average AQI will increase by less than seven. However, if the secondary industries GDP increases from the 75th percentile to the 99th percentile, then the annual average AQI will increase by 28, as is shown in Table 5.1 and Table 5.2. An increase of 28 in the AQI indicates that the annual average concentrations of the main air pollutants will increase by at least 28 $\mu g/cm^3$, which will lead to a significant health impact.

According to the regression results, if a city is developing pollution-intensive industries, the potential impact on air quality is about three times larger than developing non-pollution-intensive industries. AQI increase by 21 implies daily PM_{10} concentration increases by 42 $\mu g/cm^3$, or NO_X concentration increases by

Table 5.1: Estimated Impact of GDP Growth on AQI

(a) Per Area GDP

	Percentiles	Predicted Δ AQI
25 %	0.496	–
50 %	1.153	+0.585
75 %	2.591	+1.241
90 %	8.391	+4.462
99 %	24.566	+7.822

Unit: 10 million yuan/sq.km

(b) Per Area Secondary Sector GDP

	Percentiles	Predicted Δ AQI
25 %	0.237	–
50 %	0.580	+2.153
75 %	1.359	+4.727
90 %	2.548	+6.774
99 %	10.866	+32.525

Unit: 10 million yuan/sq.km

Based on the estimated results in 4.1 Chapter 4.2, if per area GDP of a city increase from 25th percentile in our sample to 50th percentile, its annual average AQI will increase by 0.5. However, if per area secondary industry GDP of a city increase from 25th percentile in our sample to 50th percentile, the annual average AQI will increase by around 2.2 which is much larger.

Table 5.2: Estimated Impact of Increasing Industry Output on AQI

(a) Pollution-Intensive Industries

	Percentiles	Predicted Δ AQI
25 %	0.251	–
50 %	0.718	+1.253
75 %	1.885	+2.131
90 %	4.009	+5.699
99 %	11.918	+21.220

Unit: 10 million yuan/sq.km

(b) Non-Pollution-Intensive Industries

	Percentiles	Predicted Δ AQI
25 %	0.115	–
50 %	0.513	+0.299
75 %	1.359	+0.635
90 %	2.548	+0.892
99 %	10.866	+6.239

Unit: 10 million yuan/sq.km

If a city is developing pollution-intensive industries, the potential impact on air quality is about 3 times larger than developing non-pollution-intensive industries. AQI increase by 21 implies daily PM_{10} concentration increases by 42 $\mu g/cm^3$, or NO_X concentration increases by 17 $\mu g/cm^3$, or SO_2 concentration increases by 21 $\mu g/cm^3$, or O_3 concentration increases by 25 $\mu g/cm^3$, or CO concentration increases by around 4 mg/cm^3.

17 $\mu g/cm^3$, or SO_2 concentration increases by 21 $\mu g/cm^3$, or O_3 concentration increases by 25 $\mu g/cm^3$, or CO concentration increases by around 4 mg/cm^3.

Table 5.3 shows the slopes of the air quality degradation curves for several cities in different years. The selected cities are Beijing, Shenzhen, Shenyang, and Hefei, two of which are famous, developed cities and two of which are relatively small cities. The table also presents the potential AQI changes caused by GDP increasing by 10%, 7%, or 1 billion Yuan/sq.km.

As shown in the table, Shenzhen is enjoying a negatively correlated economic growth and air quality degradation, while the other three cities are suffering from decreases in air quality caused by economic growth, especially Hefei. Although Beijing has the highest GDP among the four cities, Shenzhen is the only city that has reached the declining part of the air quality degradation curve. This fact further confirms the importance of applying the per area GDP model instead of the per capita model. The density of the economy in Shenzhen is much higher than in Beijing. Thus, the marginal effect of economic development in Shenzhen becomes negative after 2009. For all cities, the marginal effect is decreasing.

Since 2000, China has been developing its western area. And more recently, the government pushes the "One Belt, One Road" project. I suspect that developing the western area could lead to significant air quality degradation. The Western Development Program covers six provinces (Gansu, Guizhou, Qinghai, Shaanxi, Sichuan, and Yunnan), five autonomous regions (Guangxi, Inner Mongolia, Ningxia, Tibet, and Xinjiang), and one municipality (Chongqing). This study tries to estimate how this development will affect the air quality in western China.

Table 5.4 simulates the impact of economic growth on air quality in western cities and finds that if the economy of western cities were to become as developed as eastern cities, the AQI of western cities would be 3.7 times larger, based on the regression results. If only the secondary sector of the economy were to become as developed as eastern cities, the air quality would be much more serious. The AQI would increase by 12.7, which implies the concentrations of main pollutants would increase by at least 12.7 $\mu g/cm^3$. Thus, the regulation of secondary industry, especially pollution-intensive industries, is important in the development of western areas in China.

Table 5.3: Marginal Effect of Economic Growth on Air Quality Degradation for Several Cities

(a)

CityName	Year	AQI	GDP	GDPperA	$\partial AQI/\partial GDPperA$
Beijing	2000	100.780	3.105	1.847	1.242
	2001	112.769	3.631	2.161	1.232
	2002	112.112	4.289	2.553	1.219
	2003	97.553	4.879	2.904	1.207
	2004	103.363	5.725	3.489	1.188
	2005	98.593	6.750	4.116	1.167
	2006	110.447	7.886	4.808	1.144
	2007	99.989	9.264	5.649	1.116
	2008	87.483	10.349	6.310	1.094
	2009	84.986	12.067	7.358	1.059
	2010	85.795	13.471	8.214	1.031
	2011	81.128	15.203	9.264	0.996
	2012	78.503	17.182	10.470	0.956
Base on 2012 Beijing					
ΔGDP	+10%			Δ AQI	0.665
	+7%				0.468
	+10 million Yuan/sq.km				0.636

(b)

CityName	Year	AQI	GDP	GDPperA	$\partial AQI/\partial GDPperA$
Shenzhen	2000	51.597	1.635	8.391	1.025
	2001	54.835	1.913	9.817	0.978
	2002	52.542	2.243	11.509	0.921
	2003	58.682	2.821	14.445	0.824
	2004	63.619	3.248	16.632	0.751
	2005	53.507	4.795	24.566	0.488
	2006	54.192	5.647	28.917	0.343
	2007	54.435	6.399	32.766	0.216
	2008	52.817	7.269	37.220	0.068
	2009	50.061	8.143	40.877	-0.054
	2010	49.575	9.146	45.911	-0.221
	2011	49.898	10.763	54.032	-0.490
	2012	46.639	12.446	62.326	-0.766
Base on 2012 Shenzhen					
ΔGDP	+10%			Δ AQI	-4.594
	+7%				-3.113
	+10 million Yuan/sq.km				-0.671

(c)

CityName	Year	AQI	GDP	GDPperA	$\partial AQI/\partial GDPperA$
Shenyang	2000	89.000	1.098	0.846	1.275
	2001	113.294	1.211	0.933	1.273
	2002	115.893	1.392	1.072	1.268
	2003	95.401	1.562	1.204	1.264
	2004	95.223	1.804	1.390	1.257
	2005	84.711	2.019	1.555	1.252
	2006	84.346	2.448	1.886	1.241
	2007	85.163	3.031	2.335	1.226
	2008	85.169	3.594	2.769	1.212
	2009	81.313	4.238	3.265	1.195
	2010	76.690	4.789	3.690	1.181
	2011	74.930	5.535	4.264	1.162
	2012	72.712	6.345	4.888	1.141
Base on 2012 Shenyang					
ΔGDP	+10%			Δ AQI	0.383
	+7%				0.268
	+10 million Yuan/sq.km				0.776

(d)

CityName	Year	AQI	GDP	GDPperA	A
Hefei	2000	77.786	0.319	0.439	1.289
	2001	78.036	0.356	0.490	1.287
	2002	82.615	0.410	0.547	1.285
	2003	75.891	0.473	0.630	1.283
	2004	79.560	0.560	0.796	1.277
	2005	72.025	0.827	1.176	1.264
	2006	73.564	1.043	1.484	1.254
	2007	82.796	1.256	1.786	1.244
	2008	92.405	1.550	2.200	1.230
	2009	80.714	2.087	2.962	1.205
	2010	81.099	2.579	3.659	1.182
	2011	81.340	3.402	2.977	1.205
	2012	73.289	4.002	3.496	1.187
Base on 2012 Hefei					
ΔGDP	+10%			Δ AQI	0.287
	+7%				0.201
	+10 million Yuan/sq.km)				0.811

Unit of GDPperA: 10 billion Yuan/sq.km. Unit of GDP: 100 billion Yuan. These tables represent 4 examples showing the marginal effect of economic growth on air quality degradation.

Table 5.4: Estimated Effect of Western Development Program

(a)

	GDP perArea	AQI	ΔAQI, if as developed as Central China	ΔAQI, if as developed as The East Coast
Western China	1.206	68.0	+ 0.7	+ 3.7
Central China	1.456	67.8	–	+ 3.0
The East Coast	3.452	62.1	–	–

Unit: 10 million yuan/sq.km

(b)

	Sec.GDP perArea	AQI	ΔAQI, if as developed as Central China	ΔAQI, if as developed as The East Coast
Western China	0.446	68.0	+ 3.2	+ 12.5
Central China	0.961	67.8	–	+ 9.3
The East Coast	2.578	62.1	–	–

Unit: 10 million yuan/sq.km

China is developing its western area. Previous analysis has shown the potential result of economic growth, thus I suspect that the developing the western area might lead to significant air quality degradation. These tables simulates the impact of economic growth on air quality on western cities and suggests that If the secondary industries in western cities were as developed as in eastern cities, the air quality will be 12.5 larger based on the regression results. Thus the regulation of secondary industry, especially the pollution-intensive industries are important in the development of western area in China.

CHAPTER 6

CONCLUSION

This study analyzes data from 118 Chinese cities during the years 2000 to 2012 and finds a quadratic relationship between air quality degradation and economic growth. Although previous studies also found a quadratic relationship, these other studies focused on finding the turning point of economic growth: the point where growth begins to improve air quality. This study addresses an endogenous problem and identifies the impact of economic growth and industrial output on air quality degradation

This study finds a significant linear relationship between pollution-intensive industrial outputs and AQI. Accordingly, the negative impact on air quality of secondary industry growth is mostly driven by pollution-intensive industries. The marginal effect of pollution-intensive industrial output is more than three times higher than non-pollution-intensive industrial output. Considering the flat impact of non-pollution-intensive industries, air quality could improve if the secondary industry becomes cleaner.

According to our estimate, if China continues to grow at about 10% annually, air quality will continue to decline in most areas. For cities such as Beijing, a 10% increase in its GDP would lead to an AQI increase of about 0.665, on average. For a relatively undeveloped city such as Hefei, a 10% increase in GDP would lead to an annual average AQI increase of 0.287. Among the 118 Chinese cities in the study, only Shenzhen is enjoying economic growth. According to our estimation, a 10% increase in its GDP will lead to an AQI decrease of 4.59, on average.

The impact of pollution-intensive industries on air quality is about three times higher than for non-pollution-intensive industries. If the pollution-intensive industries in western China become as developed as the industries on the eastern coast, then the annual average AQI of western cities would increase by 8.5. AQI increase by 8.5 implies daily PM_{10} concentration increases by 17 $\mu g/cm^3$, or NO_X concentration increases by 8 $\mu g/cm^3$, or SO_2 concentration increases by 8.5 $\mu g/cm^3$, or O_3 concentration increases by 8.5 $\mu g/cm^3$, or CO concentration increases by around 2 mg/cm^3. These increase will lead to serious health implications.

Based on the estimate results, this study predicts a potential of considerable air quality impact of the Western Development Program and the "One Belt, One Road" project. To curb the environmental impact of 'New Silk Roads', policy-makers should consider this potential and increase environmental regulation in the western China.

APPENDIX A

DATA APPENDIX

A.1 Definition of AQI

The meaning of AQI has been explained in Chapter 2 of the text. According to official documents published by the Chinese government, notably *AQI and Health Implications (HJ 663-2012)*[17], the AQI is calculated based on the concentrations of SO_2, NO_x, CO, O_3 PM2.5 and PM10. This data appendix describes in further detail the relationship between AQI and pollutant concentrations. As shown in the table below, AQI values range from 0 to 500.

Table A.1: AQI Range and Corresponding Pollutant Concentrations

IAQI	SO_2 (24h)	NO_2 (24h)	PM_{10} (24h)	CO (24h)[1]	O_3 (1h)	O_3 (8h)[2]	$PM_{2.5}$ (24h)
0	0	0	0	0	0	0	0
50	50	40	50	2	160	100	35
100	150	80	150	4	200	160	75
150	475	180	250	14	300	215	115
200	800	280	350	24	400	265	150
300	1600	565	420	36	800	800	250
400	2100	750	500	48	1000	–	350
500	2620	940	600	60	1200	–	500

[1] Unit of CO concentration: mg/m^3

[2] If 8-hour-average O_3 concentration is larger than 800, then only report IAQI value for 1-hour average O_3 concentration

[3] Unit of all other pollutant concentration: $\mu g/m^3$

Based on the table, first we have one value for each of the pollutants above. These values are denoted $IAQI_p$, where p stands for the pollutant.

$$IAQI_p = \frac{IAQI_{Hi} - IAQI_{Lo}}{BP_{Hi} - BP_{Lo}}(C_p - BP_{Lo}) + IAQI_{Lo} \tag{A.1}$$

C_p : concentratin of pollutant p

BP_{Hi} : The closed value of concentration standard higher than C_p in the table above

BP_{Lo} : The closed value of concentration standard lower than C_p in the table above

$IAQI_{Hi}$: The corresponding IAQI value of BP_{Hi} in the table above

$IAQI_{Lo}$: The corresponding IAQI value of BP_{Lo} in the table above

Second, the daily AQI is the maximum value of all $IAQI_p$ values.

$$AQI = maxIAQI_p \tag{A.2}$$

where p is index of pollutant, 1-7.

A.2 City-level annual air quality index (AQI)

City-level daily air quality index data is published on the website of the Ministry of Environmental Protection of the Peoples Republic of China. Beginning in 2000 when 45 cities made public their air quality index data for the first time, cities in China successively began to release their air quality data. AQI data from 120 cities are available through 2012. However, two of these cities economic data are not available. Thus the panel only includes 118 cities in total. Therefore, the unbalanced database includes 1,050 observations in total, with the number of observations in each year varying from 45 to 118, as shown in Table 2.1.

We obtain annual AQI data by averaging the daily AQI data by year. As shown in Table 2.1, the number of cities in the sample changes over the years. Figure A.1 compares the trend of the 41-city average AQI and full sample average. This suggests that the decreasing trend of AQI is not caused by changes in the sample

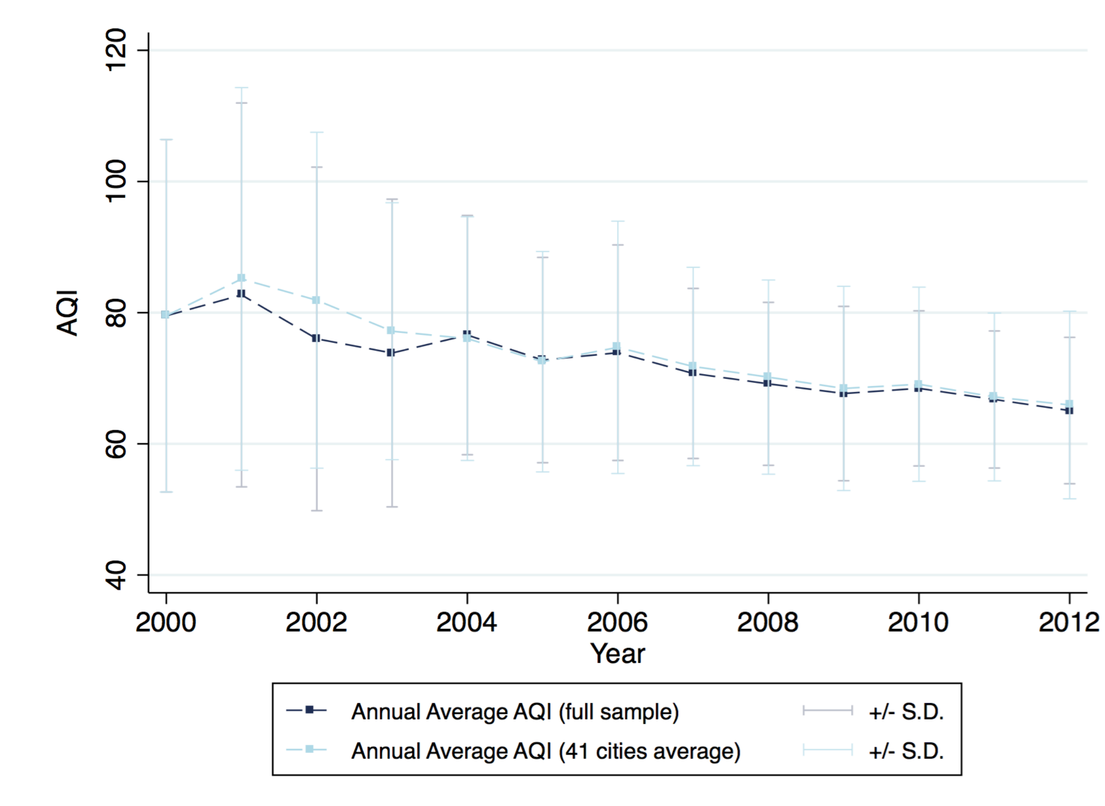


Figure A.1: AQI across years

A.3 City-level economic and demographic statistics data

The annual economic and demographic statistics data come from China Data on-line database, which contains the main city-level economic and statistical data for most cities in China since 1996. Downloaded variables include: Gross Domestic Product, Primary Industry Percentage, Secondary Industry Percentage, Tertiary Industry Percentage; Total Population (at year-end), Land Area, and Population Density. We merged these municipal-level annual statistics with the AQI data by the cities unique IDs. After dropping the unmatched cities, we got the unbalanced panel data from 2000 to 2012. The statistics for this data are shown in Table 2.2. All the variables measured by monetary values are converted into 1999 price of RMB.

A.4 Firm Survey Data and City-level Industry Outputs

The firm survey data are available for 19982009 and 20112012. Data for 2010 is missing. Only private firms of which annual revenues are larger than 5 million yuan and state-owned firms are surveyed. From 2000 to 2012, the raw data, a firm-level annual survey data, includes 3,592,529 observations (firm*year) in total, with the number of observations (firms) in each year varying from 163,000 to 345,000, as shown in Table A.2.

Some 6,581 observations are dropped due to a missing city ID. (There are 49,423 more observations that are missing a city ID; but these observations were able to be located by the city using firms zip codes.) Available variables include firms basic information, production and sales data, and financial status. We keep the following variables: city ID, zip code, firm type, and the firms annual output and export data.

Table A.2: Summary of the Firm Survey Data

Year	2000	2001	2002	2003	2004	2005	2006
Number of Firms	162,885	171,256	181,557	196,221	279,085	271,835	301,960
Year	2007	2008	2009	2010	2011	2012	
Number of Firms	336,768	411,406	302,776	0	311,314	344,874	

From this dataset, we obtained outputs and export values of different industry types. Statistics on outputs by different industries are shown in Table A.3. While outputs data are used as independent variables in the analysis, the export values are used to construct IVs following the steps in Chapter 3.2.2.

Table A.3: Statistics of Industry Output (billion Yuan)

cic Code	Industry	Obs.	Mean	Std.Dev.	Min	Max
13	Food and Kindred Products Processing	562	5.551	7.590	0.006	64.336
14	Food Making	562	2.497	3.916	0.000	28.840
15	Beverages	562	1.960	2.745	0.000	17.663
16	Tobacco Products	562	2.184	4.481	0.000	35.272
17	Textile Mill Products	562	7.510	17.131	0.000	149.790
18	Apparel and Other Textile Products	562	3.753	7.215	0.000	50.006
19	Leather And Leather Products	562	2.351	5.715	0.000	57.385
20	Lumber and Wood Products	562	0.893	1.525	0.000	13.021
21	Furniture and Fixtures	562	0.930	2.037	0.000	19.871
22	Paper and Allied Products	562	2.427	4.225	0.000	33.927
23	Printing And Publishing	562	1.162	2.010	0.000	16.462
24	Pens, Pencils, Office, and Art Supplies	562	1.088	2.364	0.000	16.479
25	Petroleum And Coal Products	562	7.317	15.129	0.000	97.369
26	Chemicals And Allied Products	562	10.395	18.066	0.001	162.150
27	Drugs	562	3.012	3.983	0.000	26.861
28	Cellulosic manmade fibers	562	1.858	5.708	0.000	57.295
29	Rubber Products	562	1.572	3.029	0.000	21.513
30	Misc.Plastics Product	562	3.580	6.092	0.000	46.243
31	Stone,Clay,And Glass Products	562	5.428	8.389	0.012	77.150
32	Black Metal Industries	562	10.442	20.155	0.000	158.590
33	Non-Ferrous Metal Industries	562	4.064	7.366	0.000	59.660
34	Fabricated Metal Products	562	4.283	8.218	0.000	81.220
35	Industrial Machinery And Equipment	562	7.890	15.937	0.000	186.312
36	Special industry machinery,nec	562	4.386	6.725	0.000	59.902
37	Transportation Equipment	562	13.542	28.451	0.000	233.014
39	Electronic and Other Electric Equipment	562	10.228	18.592	0.000	156.099
40	Electronic computers	562	24.107	77.294	0.000	798.836
41	Instruments And Related Products	562	2.297	5.646	0.000	49.485
42	Miscellaneous ManufacturingIndustries	562	1.424	2.869	0.000	33.499
43	Scrap and Waste Materials Recycling and Processing	562	0.124	0.573	0.000	7.506

Unit: 1 billion Yuan. Note: All the variables measured by monetary values are converted into 1999 price of RMB.
Data source: Industry Survey in China, 1998-2007

Next we separated the industries into pollution-intensive and non-pollution-intensive. (A list of these industries is shown in Table A.4.) The final industry activities dataset is a city-year panel data for 20002009 and 2012012, including six variables: total output, total export, output for pollution-intensive industries, output for non- pollution-intensive industries, export value for pollution-intensive industries, and export value for non-pollution-intensive industries.

Table A.4: Pollution-Intensive and Non-Pollution-Intensive Industries

(a)

Code	Pollution-Intensive Industries
15	Beverages
17	Textile Mill Products
19	Leather And Leather Products
22	Paper and Allied Products
25	Petroleum And Coal Products
26	Chemicals And Allied Products
27	Drugs
28	Cellulosic manmade fibers
29	Rubber Products
30	Misc.Plastics Product
31	Stone,Clay,And Glass Products
32	Black Metal Industries
33	Non-Ferrous Metal Industries

(b)

Code	Non-Pollution-Intensive Industries
13	Food and Kindred Products Processing
14	Food Making
16	Tobacco Products
18	Apparel and Other Textile Products
20	Lumber and Wood Products
21	Furniture and Fixtures
23	Printing and Publishing
24	Pens, Pencils, Office, and Art Supplies
34	Fabricated Metal Products
35	Industrial Machinery And Equipment
36	Special industry machinery,nec
37	Transportation Equipment
39	Electronic and Other Electric Equipment
40	Electronic Computers
41	Instruments and Related Products
42	Miscellaneous Manufacturing Industries
43	Scrap and Waste Materials Recycling

APPENDIX B

ROBUSTNESS CHECK

B.1 Alternative Instrumental Variables

Table B.1 compares estimates using the main IVs and the alternative IVs. Construction of the IVs are explained in Chapter 3.2.2. Estimation results using alternative IVs are similar to the main model but have weaker first-stage results.

Table B.1: Relationship between AQI and per area Secondary Industry GDP

	Results from OLS		Results from IV (GDP)		Results from IV (Import)	
	(1)	(2)	(1)	(3)	(2)	(4)
	AQI	AQI	AQI	AQI	AQI	AQI
Sec.GDPperArea	0.6367	2.1946**	1.0193	6.4320***	1.1338	6.1905***
	(0.4608)	(1.0900)	(0.8434)	(2.1822)	(0.9313)	(2.1312)
Sec.GDPperArea^2		-0.0623**		-0.1876***		-0.1785***
		(0.0306)		(0.0656)		(0.0636)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
N	1009	1009	1009	1009	1009	1009
$adj.R^2$	0.236	0.241	0.131	0.097	0.130	0.101

Dependent variable of all the regressions AQI; Unit of Sec.GDPperArea: 10 million yuan/sq.km Standard errors are adjusted for 118 clusters in city. Sigificance levels are indicated as * p<0.10, ** p<0.05, *** p<0.01. First-stages of column 3 and 4 are reported in Table 4.3. First-stages of column 5 and 6 are reported in Table B.2

Table B.2: First Stage of the 2SLS regression in Table B.1. (Using import value to construct instrumental variables)

	(1)	(2)	
	Linear Model	Quadratic Model	
	Sec.GDPperArea	Sec.GDPperArea	Sec.GDPperArea^2
IV: $Weighted.Import_{i,t}/Area_i$	0.0034	0.1580***	2.5882***
	(0.0490)	(0.0452)	(0.6743)
IV: $EI_{i,2000} \times Weighted.Import_{i,t}/Area_i$	3.3486*	-4.7891***	-157.6551***
	(1.7663)	(1.4549)	(24.6527)
IV: $(Weighted.Import_{i,t}/Area_i)^2$		-0.0004**	-0.0092***
		(0.0002)	(0.0031)
IV: $(EI_{i,2000} \times Weighted.Import_{i,t}/Area_i)^2$		0.8085***	29.2891***
		(0.0965)	(1.9908)
Controls	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
City FE	Yes	Yes	Yes
N	1009	1009	1009
$adj.R^2$	0.627	0.738	0.758
F-test of excluded instruments:			
F(2,117) or F(4,117)=	10.88	1397.32	1511.31
Prob.>F =	0.0000	0.0000	0.0000
Sanderson-Windmeijer multivariate F-test of excluded instruments:			
F(2,117) or F(4,117) =	10.88	9.17	17.42
Prob.>F =	0.0000	0.0000	0.0000

Number of groups 118 (cities); Number of years 12 (2001-2012) Standard errors are adjusted for 118 clusters in city. Significance levels are indicated as * p<0.10, ** p<0.05, *** p<0.01 According to the F test, the IVs are strong and valid for "Sec.GDPperA" and its square term. But compared to Table 4.3, using import values to construct instrumental variables gives a weaker first-stage.

B.2 Alternative Independent Variables

Two candidates are considered for the independent variable: per capita GDP and per area GDP. After preliminary research, this study used per area GDP as its main independent variable because this factor has stronger first-stage results and more robust second-stage results. This section reports on the results of using per capita GDP as an independent variable. The results are consistent with the main results but less significant and have weaker first-stages.

Table B.3: Relationship between AQI and per capita Secondary Industry GDP

	(1) AQI	(2) AQI	(3) AQI	(4) AQI	(5) AQI	(6) AQI	(7) AQI	(8) AQI
$\frac{Sec.GDP}{Capita}$	1.5400***	2.1739	5.9628*	10.9766**				
	(0.5671)	(1.3365)	(3.3545)	(4.3104)				
$(\frac{Sec.GDP}{Capita})^2$		-0.0280		-0.2192				
		(0.0369)		(0.1370)				
$\frac{Sec.GDP}{Area}$					0.6367	2.1946**	1.0193	6.4320***
					(0.4608)	(1.0900)	(0.8434)	(2.1822)
$(\frac{Sec.GDP}{Area})^2$						-0.0623**		-0.1876***
						(0.0306)		(0.0656)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IVs			Yes	Yes			Yes	Yes
N	1009	1009	1009	1009	1009	1009	1009	1009
$adj.R^2$	0.246	0.246	0.017	-0.035	0.236	0.241	0.131	0.097

Unit of Sec.GDPperArea: 10 million yuan/sq.km Standard errors are adjusted for 118 clusters in city. Significance levels are indicated * p<0.10, ** p<0.05, *** p<0.01. First-stage results of column 7 and 8 are reported in Table 4.3 and first-stages of column 3 and 4 are reported in Table B.2

Table B.4: First Stage of the 2SLS regression in Table B.3.

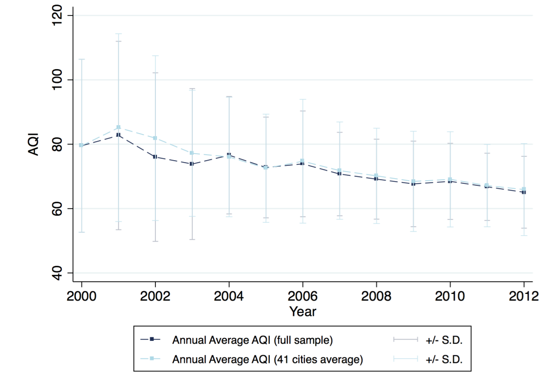
	(1)	(2)	
	Linear Model	Quadratic Model	
	Sec.GDPperc	Sec.GDPperc	Sec.GDPperc^2
IV: $Weighted.GDP_{i,t}/Area_i$	0.6852	2.8786	105.3471
	(0.6039)	(1.8671)	(72.8156)
IV: $EI_{i,2000} \times Weighted.GDP_{i,t}/Area_i$	6.2860	23.6852	-575.5614
	(17.6849)	(34.8754)	(1180.2439)
IV: $(Weighted.GDP_{i,t}/Area_i)^2$		-0.1498	-5.1998
		(0.0910)	(3.3422)
IV: $(EI_{i,2000} \times Weighted.GDP_{i,t}/Area_i)^2$		-8.1310	1026.7284
		(32.3030)	(1124.5501)
Controls	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
City FE	Yes	Yes	Yes
N	1009	1009	1009
$adj.R^2$	0.658	0.689	0.368
F-test of excluded instruments:			
F(2,117) or F(4,117)=	2.73	4.38	3.26
Prob.>F =	0.0697	0.0025	0.0143
Sanderson-Windmeijer multivariate F-test of excluded instruments:			
F(2,117) or F(4,117) =	2.73	6.67	8.25
Prob.>F =	0.0697	0.0003	0.0001

Number of groups 118 (cities); Number of years 12 (2001-2012) Standard errors are adjusted for 118 clusters in city. * p<0.10, ** p<0.05, *** p<0.01 According to the F test, the IVs are strong and valid for "Sec.GDP per capita" and its square term.

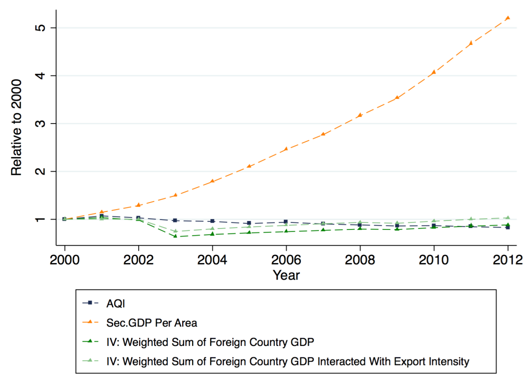
B.3 Analysis on the Balanced Subsample

This study is executed on an unbalanced panel data. Although we used fixed effects to control for the panel differences across years, the estimated impacts can be still biased by sample selection. As shown in Figure B.1, the average trend of full samples and subsamples are slightly different.

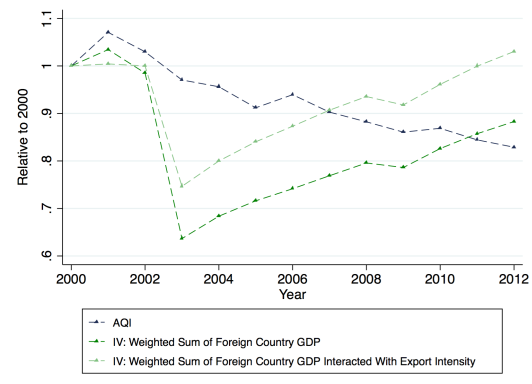
Table B.5 reports results of analysis on the balanced subsample. The results are consistent with the main results but less significant.



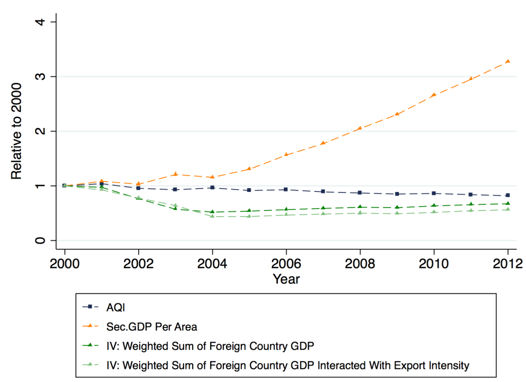
(a) AQI across years



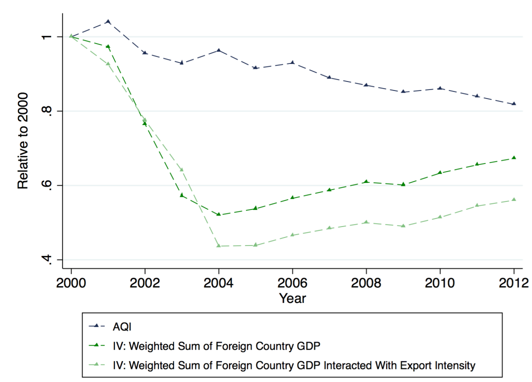
(b) Independent variable and IVs (balanced subsample)



(c) Dependent variable and IVs (balanced subsample)



(d) Independent variable and IVs (full sample)



(e) Dependent variable and IVs (full sample)

Figure B.1: Variations of IVs and the dependent variable across years

Table B.5: Analysis on the balanced subsample

	(1)	(2)	(3)			(4)		(5)	
			1^{st} stage		2^{nd} stage	1^{st} stage	2^{nd} stage	1^{st} stage	2^{nd}
	AQI	AQI	$\frac{Sec.GDP}{Area}$	$(\frac{Sec.GDP}{Area})^2$	AQI	$\frac{PI-Output}{Area}$	AQI	$\frac{NPI-Output}{Area}$	AQI
$\frac{GDP}{Area}$	0.0782	0.0448							
	(0.1448)	(0.5591)							
$(\frac{GDP}{Area})^2$		0.0005							
		(0.0070)							
$\frac{Sec.GDP}{Area}$					5.6407				
					(4.0575)				
$(\frac{Sec.GDP}{Area})^2$					-0.1557				
					(0.1190)				
$\frac{PI-Output}{Area}$							2.5371		
							(1.8172)		
$\frac{NPI-Output}{Area}$									0.6666
									(0.4612)
IV: $\sum GDP$			0.1484*	4.4655**		0.0014		-0.5797*	
			(0.0869)	(2.0698)		(0.0025)		(0.2931)	
IV: $EI \times \sum GDP$			-7.7550*	-508.0560***					
			(4.5984)	(150.3263)					
IV: $(\sum GDP)^2$			-0.0007***	-0.0186***					
			(0.0002)	(0.0044)					
IV: $(EI \times \sum GDP)^2$			3.3849***	151.4364***					
			(0.5531)	(20.0848)					
IV: PI-$EI \times \sum GDP$						0.5082***			
						(0.0977)			
IV: NPI-$EI \times \sum GDP$								4.6005**	
								(2.2691)	
N	492	492	492	492	492	450	450	450	450
$adj.R^2$	0.379	0.378	0.845	0.870	0.250	0.629	0.223	0.587	0.274

Dependent variable of all the regressions AQI; Unit of Sec.GDPperArea: 10 million yuan/sq.km

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